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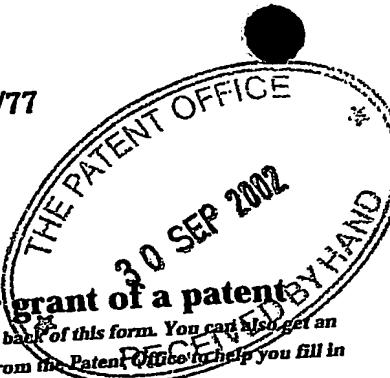
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Dated 3 October 2003

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1/77  
 10 OCT 2002 752036-8 D02890  
 P01/7700 0.00-0222624.9

The Patent Office

Cardiff Road  
 Newport  
 South Wales  
 NP9 1RH

1. Your reference

RSJ07522GB

0222624.9

30 SEP 2002

2. Patent application number  
*(The Patent Office will fill in this part)*

3. Full name, address and postcode of the or of each applicant (*underline all surnames*)

The Welding Institute  
 Granta Park  
 Great Abington  
 Cambridge, CB1 6AL  
 GREAT BRITAIN

Patents ADP number (*if you know it*)

891572005

Great Britain

4. Title of the invention

SURFACE MODIFICATION

5. Name of your agent (*if you have one*)

Gill Jennings &amp; Every

"Address for service" in the United Kingdom to which all correspondence should be sent  
*(including the postcode)*

Broadgate House  
 7 Eldon Street  
 London  
 EC2M 7LH

Patents ADP number (*if you know it*)

745002

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (*if you know it*) the or each application number

Country

Priority application number  
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Date of filing  
*(day / month / year)*

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Number of earlier application

Date of filing  
*(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (*Answer 'Yes' if*  
 a) *any applicant named in part 3 is not an inventor, or*  
 b) *there is an inventor who is not named as an applicant, or*  
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Patents Form 1/77

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Continuation sheets of this form

Description 12

Claim(s) 2

Abstract

Drawing(s) 6 26

- 
10. If you are also filing any of the following,  
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Priority documents

Translations of priority documents

Statement of inventorship and right  
to grant of a patent (*Patents Form 7/77*)

Request for preliminary examination  
and search (*Patents Form 9/77*)

Request for substantive examination  
(*Patents Form 10/77*)

Any other documents  
(please specify)

NO

11. For the applicant  
Gill Jennings & Every

I/We request the grant of a patent on the basis of this application

Signature

Date

30/09/02

12. Name and daytime telephone number of  
person to contact in the United Kingdom

SKONE JAMES, Robert Edmund  
020 7377 1377

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SURFACE MODIFICATION

The use of power beams, for example electron and laser  
5 beams for surface modification is already well known.  
Several different methods exist for changing the surface  
properties of a material in which a power beam is used to  
remove, chemically modify, or displace material on the  
surface of the work. Several of these are already subject  
10 to patent applications and patent grants.

In the conventional EB drilling process for most  
metals or other materials which exhibit a liquid phase, the  
process is applied as follows. First, a high power  
density beam makes a blind "keyhole" in the material. This  
15 "keyhole" typically consists of a narrow, deep cavity. On  
the sides of the cavity there is a layer of molten  
material. The cavity is held open predominately by the  
vapour pressure of the material, which will be at or near  
its boiling point in the area of highest beam power  
20 density. Second, the beam is allowed to dwell for a  
sufficient length of time that the cavity becomes through  
penetrating rather than blind. Third, the beam is allowed  
to dwell a little longer at the same location, so that the  
beam impinges on backing material that is close-fitting to  
25 rear of the work. This backing material is volatile, and  
produces a burst of gaseous material that expels almost all  
of the molten material from the sides of the hole.

It should be noted that this type of drilling  
operation cannot produce clean "blind" holes because there  
30 is no force present which is capable of expelling all the  
liquid material.

In the case of a material that does not exhibit a  
liquid phase, or may be chemically converted directly to a  
gaseous phase a drilling or cutting operation may be  
35 accomplished without backing material. In this instance  
blind holes may be made.

Likewise a "gas assist" in which a jet of gas is applied to the molten material in order to displace it for cutting and drilling purposes is also employed in many cases, e.g. using a laser.

5 Various methods exist which include the use of power beams to remove material from the surface of the work so as to leave upstands of essentially unaltered material, and in this way a functional surface may be obtained.

10 Techniques also exist in which the material may be displaced in the liquid phase to alter the functionality of the surface. In one variant, the material is textured by a power beam that is either stationary with respect to the surface of a moving workpiece, or is moved relative to the surface in the same direction as the workpiece motion  
15 within a fixed frame of reference. In this way usually shallow cavities of a round or elongated shape, with approximately uniform raised edges are made. The surface textures incorporating features of this type are utilised in the preparation of rolls for use in steel mills, in  
20 which the texture is imparted to the rolled steel product. In a second "surface texturing" process, the electron (or laser) beam is manipulated in multiple directions at the site of each cavity, with the result that the displaced material can be manipulated in a specific fashion. If  
25 adjacent features are created whilst the previous ones are still molten, or at least still very hot, displaced molten material from different cavities may be combined, or the entire surface can be well fused. This second technique is therefore capable of making a wide variety of functional  
30 surfaces.

Both the material displacement techniques outlined above tend to produce characteristic surfaces. In the former case, the displaced material is uniformly distributed only if the cavities are relatively shallow in  
35 relation to their diameter. In the second case, the holes may be of comparable depth in relation to their width, provided the material displaced from them is removed from

the cavity in the right way. The displaced material from the holes, alone or in combination with other molten displaced material from adjacent holes, solidifies in characteristic formations. These are similar to one another only in the fact that their shape is dictated to some extent by surface tension forces.

In most metals, the displaced material tends where possible to adopt a quasi-spherical shape. The connection between the displaced material and the substrate, and thus the shape of the redeposited displaced material, is influenced by the wetted area and temperature of both the substrate and the displaced material. The overall effect is that in most metals, upstanding features above the original substrate surface are limited in their height/width ratio. In particular, the height of any given area of redeposited material above the original substrate surface is most unlikely to significantly exceed its width.

In the present "surface sculpting" invention, a new power beam surface treatment is described, in which a novel treatment is used to predominantly displace material in the liquid phase in order to create novel types of surface. In the present invention, a location on the workpiece surface is exposed to a moving power beam in a particular way on two or more, preferably numerous, occasions. In contrast to the previous methods described, the displaced material from each location is allowed to substantially solidify in a new position before the power beam is used at the same or a neighbouring location again.

The effect of this is that the displaced material from one visit of the beam to a particular location on the workpiece surface may subsequently be overlapped by more displaced material. This can either be more material from the same location, or more material displaced from an alternate location. Likewise the cavities formed may also be overlapped to produce a new type of surface.

The result of this novel process is that the usual constraints imposed upon the geometry of the solidified

material (and the cavities also created) described above are no longer apparent. Using this technique, new features may be "grown" on the surface by using successive visits of the beam to a particular location. These features may be 5 many times greater in height than width, in contrast to those manufactured by the existing techniques.

In accordance with the present invention, a method of modifying the surface of a workpiece comprises:

- 1) causing relative movement between a power beam 10 and the workpiece so that an elongate region of the workpiece is melted and the melted material displaced to form a hump at one end of the region and a cavity at the other;
- 2) allowing the melted material to solidify; and 15 thereafter
- 3) repeating step 1) one or more times, the elongate region corresponding to each repeat intersecting the elongate region of step 1).

Some examples of methods according to the present 20 invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 illustrates a single swipe along a substrate;

Figure 2 illustrates the swipe of Figure 1 in cross-section;

25 Figures 3-5 are views similar to Figure 2 but illustrating two, three and n superimposed swipes respectively;

Figure 6 is a perspective view of the Figure 5 example;

30 Figures 7-9 illustrate a notation system;

Figure 10 illustrates the formation of a "super hump";

Figure 11 illustrates the creation of a "super hole";

Figure 12 illustrates the formation of a network of super holes and super humps;

35 Figure 13 is a photomicrograph of a super hump in austenitic stainless steel;

Figure 14 is a photomicrograph of an area of the substrate shown in Figure 13; and,

Figure 15 illustrates a larger area of the substrate shown in Figures 13 and 14.

In all these examples, the surface modification is carried out by a focussed electron beam generated using a conventional electron beam source, the beam being moved relative to a substrate. Of course, as mentioned above, the substrate could be moved relative to the beam or indeed both could be moved.

Figure 1 illustrates the formation of a single swipe in a substrate 1 such as steel. The swipe commences at the location labelled 2 in Figure 1 causing the formation of a small hump. The beam then moves in a generally linear path 5 to create a melted region 3 and terminates at a point 4 where a small crater or cavity is formed. This will result in the displacement of substrate material and this is allowed to solidify, generally while the beam is creating swipe(s) in other locations. The beam can then return to 20 this swipe location to repeat the swipe either exactly or in other ways as will be described in more detail below.

Each swipe is likely to incorporate a predominantly linear motion in relation to the work 1, whose length is typically several times greater than the diameter of the beam. If the swipe path 3 is curved, a typical minimum radius of curvature would be comparable (but not limited) 25 to the beam diameter.

Each swipe is capable of generating a small pool of molten material, which is translated across the surface of the work 1. In this pool, there is typically a significant surface shaping force, from the vapour pressure arising 30 from the beam incident on the metal surface. The effect of each swipe is to displace a small amount of material. Typically a small amount of surplus material is seen as a hump 2 at the start of the swipe. A small cavity 4 of 35 corresponding size is seen at the finish of the swipe (Figure 2).

If a second swipe is exactly superimposed over a first, both the finish cavity 4 and the start hump 2 will to a first approximation double in size (Figure 3).

5 If a third overlapping swipe is superimposed over the first two, the finish cavity 4 and start hump 2 will now be approximately three times larger than after the first swipe (Figure 4).

10 After a number n of overlapping swipes (Figures 5 and 6), the finish cavity 4 in the work 1 and the start hump 2 may be of great height/depth to width ratio. When this happens, the incident beam may no longer melt the same quantity of material at the finish crater because of an effective drop in the beam power density per unit area at the point of incidence.

15 After a number of overlapping swipes, the material at the start hump 2 may no longer be adequately chilled by the bulk owing to its now remote connection to it. This may result in no further increase in the height of the start hump with further successive swipes because each swipe now remelts nearly all the material from the previous swipe.

20 If the start positions of several different swipes are superimposed, the effect is to make a superimposed start hump many times larger than each of the finish cavities, i.e. a super hump (Figure 10).

25 If none of the finish cavities overlap at all but all of the start humps do, then the result will be a general reduction in the height of the substrate surface surrounding a sizeable start hump feature.

30 If the finish cavities of several swipes are superimposed, the result may be to make a cavity that is several times larger than each of the start humps, i.e. a super hole (Figure 11).

35 If none of the start humps overlap, but all of the finish cavities do, the effect is to make a deep cavity that is surrounded by a small plateau raised slightly above the original workpiece surface.

If the surface is plated or coated with a second material, or the work is carried out in a suitable gaseous or liquid environment, a new functional alloy may be created. In the case of a coating, successive swipes can  
5 displace material from either the coating itself, or from an exposed area of the substrate as desired. In this way, the composition and properties of a start hump may be graded from top to bottom.

If successive linear swipes are carried out at the  
10 same location, the result is usually that the start hump 2 is approximately triangular in shape. The sides of the start hump facing away from and to each side of the swipe direction are almost vertical. The other side is usually angled to the substrate surface. The finish cavity may  
15 also be of corresponding triangular shape.

If successive linear swipes are started at slightly altered locations, e.g. each one requiring a slightly different length path to reach the same finish cavity, the result will be a non-vertical start hump feature. In this  
20 case, if successively shorter swipe paths are used, the side of the start hump facing away from the swipe direction will also be angled acutely to the substrate surface. This effect may be tailored so as to produce a symmetric start hump feature.

25 Alternatively, with a successively longer swipe path, the side of the start hump facing away from the swipe direction will be inclined to the substrate surface so as to produce an overhanging feature.

If successive linear swipes are carried out at the  
30 same location but the swipes are not superimposed exactly so that there is a small displacement with each swipe in a lateral direction, the effect will be to produce a start hump that is inclined laterally to the substrate surface.

In the latter two cases, if neighbouring inclined start  
35 humps are made in such a way that they are inclined towards one another, several start humps may be fused together. This may be done in such a way as to create a "loop" or

"loops" of fused material standing proud of the substrate surface.

The geometry of the finish cavity may be controlled in a similar way, given that the beam still has line of sight access to the bottom of the cavity, which may require a complex beam/workpiece manipulation in the case of an inclined finish cavity.

10 The process is generally applied to a surface perpendicular to the incident power beam direction, but may be applied successfully at other angles to the workpiece surface in many cases.

If carried out in the correct fashion, the process allows the generation of slots in the surface of the work that are parallel-sided.

15 Slots or cavities in the work can be made to intersect one another at numerous locations. However, correct material displacement is not usually maintained if a new swipe path crosses over an existing slot.

20 In the preferred technique, "T" shaped slots are made by either the intersection of three separate finish cavities from three separate swipe paths, each carried out in turn, or by the intersection of a new finish cavity with the mid-point of an existing slot.

25 Slots may be many times deeper and longer than they are wide. In suitable section thickness, slots may be made to fully penetrate the work.

30 The minimum slot width is determined typically by the diameter of that part of the beam (the "core") which possesses sufficient power density to create the shaping force effect described above.

35 The sides of the slots formed by this process may consist entirely of remelted material, which in EB drilling parlance would be "undefined". In the surface sculpting process, the "undefined" material from each swipe usually fuses smoothly with that from previous swipes. The result is therefore a slot with remarkably smooth and parallel sides.

By applying the inventive process with a beam of appropriate diameter and power, features of almost any size may be created on any material which exhibits a stable liquid phase under the process conditions.

5 Special processing conditions may be required in those cases in which the surface tension of the liquid phase is a very strong function of temperature.

If one or more (matching or non-matching) materials is continuously added to what would normally be the "finish 10 cavity" region of the work, the net result can be upstanding features on the surface with little or no corresponding cavities if desired. Extra material may be added via the use of conventional techniques e.g. wire or powder. If material is continuously removed from the 15 "start hump" region of the work, the result can be cavities in the work with little or no upstanding material. Surplus molten material may be removed via wicking, suction or blowing (e.g. via a gas jet) or by the application of a higher power density beam which causes spontaneous eruption 20 of the molten pool and removal of material from the workpiece. In either case, material may be removed or added by using another separate element, which may comprise a consumable or disposable "palette" which is brought into close proximity to the work. In this case, the swipe path 25 would fall partially onto the work and the palette.

In the preferred case, the time between swipes at any one location is not wasted by turning the beam off. Instead the beam is used during this time to process and swipe other areas of the workpiece or alternative workpieces.

30 The minimum number of separate locations that may be simultaneously processed by a single continuous beam is dictated by the time taken for each location's swipe (or swipes) in relation to the dwell time required at each location between swipes. The maximum number is only 35 limited by the capabilities of the beam deflection/workpiece manipulation system, provided the extra cooling

afforded by a longer dwell time than is strictly necessary is tolerated.

In one case, the workpiece may be static in relation to the electron beam generator. A "global" beam deflection pattern manipulates the beam between an array of locations (e.g. a pattern comprising rows and columns of uniform spacing) on the surface of the work. At each location a "motif" deflection may be carried out, comprising one or more "swipes" as required. After a set number of repeats of the "global" deflection pattern, the process is complete, and the beam is terminated (Figures 10 to 12).

In another case, "global" and "motif" patterns are used as above. However, in this case, the workpiece is also in motion, such that upon each repetition of the "global" pattern, it is differently superimposed over the work. On each repeat, the first column of locations in the global pattern is now over virgin material, the second column is over those locations which were most recently exposed to the first column, and so on. In modifications of the this process:

- the number of columns in the "global" pattern can be made to equal the required number of visits or swipes at each location. In this way, the process may be applied continuously to a moving strip or sheet of substrate material, with an exactly equivalent net effect at each location (barring those at the start and finish of the run) in every case;
- if applied to a part of circular symmetry which is rotated during the process, an exactly equivalent action (barring the exact temperature change between two different swipes in some cases) may be obtained at every location on the work. This may be achieved provided the motion of the work is exactly synchronous with the global beam deflection, such that 360 degrees

- rotation exactly corresponds to an integer number of global pattern repeats;
- each column in the global pattern may be arranged so as to produce an equivalent swipe pattern at each location, or a different one at each location. In combination with the workpiece motion, this may be used to create more complex or inclined features on the work; or
  - if required, material may be added or removed from the work at locations which are fixed in relation to the electron gun.

Some examples of the application of the method to austenitic stainless steel are shown in Figures 13-15. Figure 13 illustrates a single super hump surrounded by six cavities. Figure 14 illustrates the location of the super hump shown in Figure 13 in relation to its immediate neighbours while Figure 15 illustrates another arrangement of super humps.

The parameters of the examples are set out in Table 1 below.

Table 1

Figure No.	Fixture No.	Acc. Volt. kV	Beam Current, mA	Time/s	Focus Pot Setting	Working Dist. mm	PRIMARY BEAM DEFLECTION			SECONDARY BEAM DEFLECTION			Material
							X	Y	Pattern	U	V	Pattern	
							Ampl.	Freq. Hz	Ampl.	Freq. Hz	Ampl.	Freq. Hz	
Fig 15, 21179	T2-143	130	2.4	20	4.05	20	0.75	25	0.75	25	0.18	1000	SUPER Q REV.3
Fig 13, 21242	T2-163	130	3.8	20	4.05	196	0.75	2	1.3	2	0.3	480	SNOWFL AKE REV 1.1

CLAIMS

1. A method of modifying the surface of a workpiece, the method comprising:

5        1) causing relative movement between a power beam and the workpiece so that an elongate region of the workpiece is melted and the melted material displaced to form a hump at one end of the region and a cavity at the other;

10      2) allowing the melted material to solidify; and thereafter

3) repeating step 1) one or more times, the elongate region corresponding to each repeat intersecting the elongate region of step 1).

15     2. A method according to claim 1, wherein each of the elongate regions of step 3) coincides substantially with the elongate region of step 1).

3. A method according to claim 1 or claim 2, further comprising forming one or more groups of elongate regions, 20 each group intersecting the elongate region of step 1).

4. A method according to claim 3, wherein the cavities of each group are substantially co-incident with the cavity of the elongate region of step 1).

5. A method according to claim 3, wherein the humps of each group are substantially coincident with the hump of the elongate region of step 1).

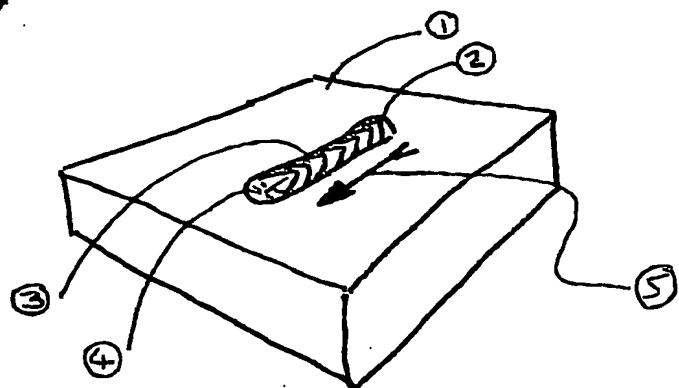
6. A method according to claim 3, wherein the groups of elongate regions and the elongate region of step 1) define a "T" shape.

25     7. A method according to any of claims 3 to 6, wherein the groups of elongate regions are arranged in a regular array.

30     8. A method according to any of the preceding claims, wherein one or more of the elongate regions are 35 rectilinear.

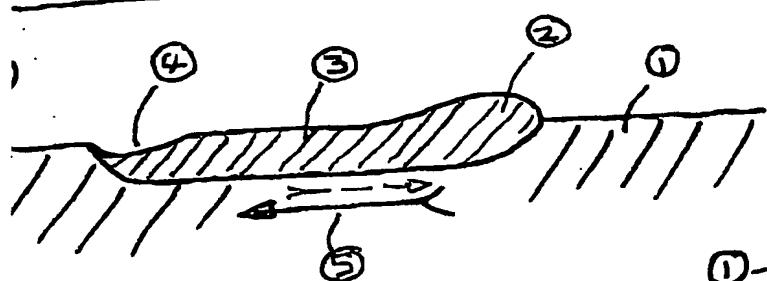
9. A method according to any of the preceding claims, wherein during step 2), the power beam forms one or more elongate regions elsewhere on the substrate.
10. A method according to any of the preceding claims,  
5 wherein the substrate is coated with another material prior to step 1) so that an alloy is formed during performance of the method.
11. A method according to any of claims 1 to 9, wherein steps 1)-3) are carried out in a gaseous atmosphere so that  
10 an alloy is formed.
12. A method of modifying the surface of a workpiece substantially as hereinbefore described with reference to any of the examples shown in the accompanying drawings.
13. A workpiece which has been modified by a method  
15 according to any of the preceding claims.

# SURFACE SCULPTING



- (1) SUBSTRATE MATERIAL
- (2) 'START HUMP'
- (3) MID-PART OF SHORT MELT-RUN OR 'SWIPE'
- (4) 'FINISH CRATER'
- (5) MELT-RUN OR 'SWIPE' DIRECTION

FIG ① A SINGLE 'SWIPE'



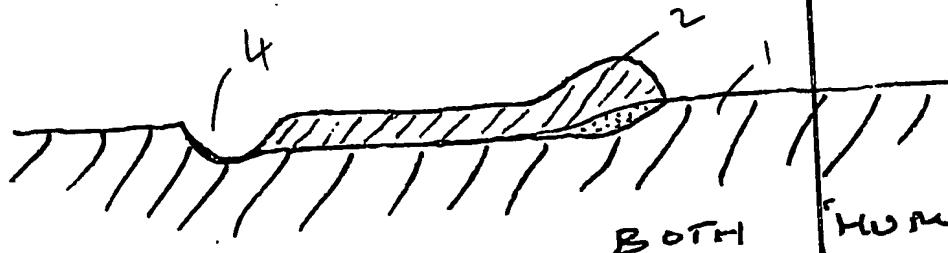
BASE MATERIAL

MELTED MATERIAL

①-⑤ AS FIG ①

FIG ② A SINGLE 'SWIPE' IN CROSS-SECTION  
NOTE EFFECT, WHICH IS TO DISPLACE MATERIAL IN REVERSE DIRECTION>-->

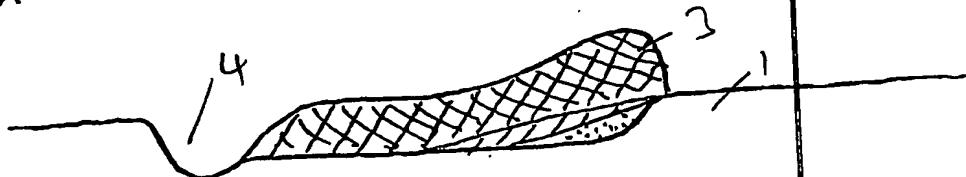
③ 2x SUPERIMPOSED 'SWIPE'S'



/// DOUBLE-MELTED MATERIAL  
::: SINGLE-MELTED MATERIAL

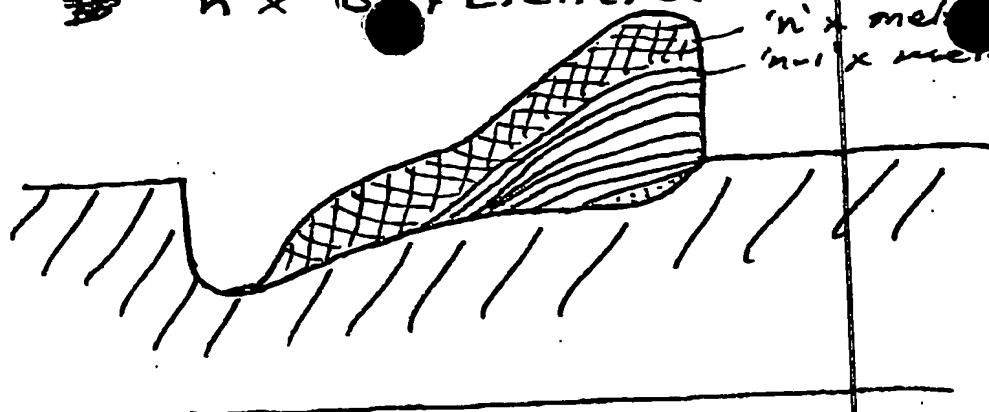
'HUMP' AND CRATER NOW LARGER

④ 3x SUPERIMPOSED 'SWIPE'S

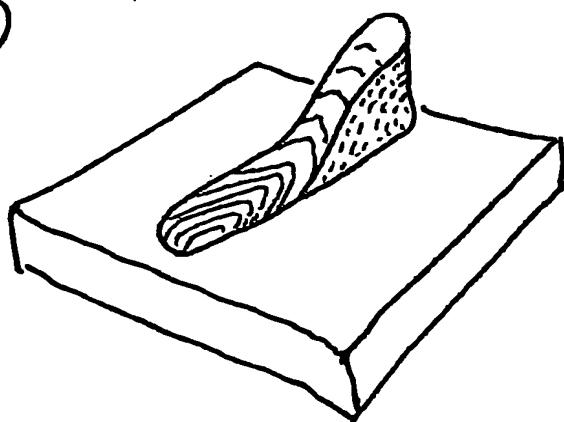


# TRIPLE-MELTED MATERIAL

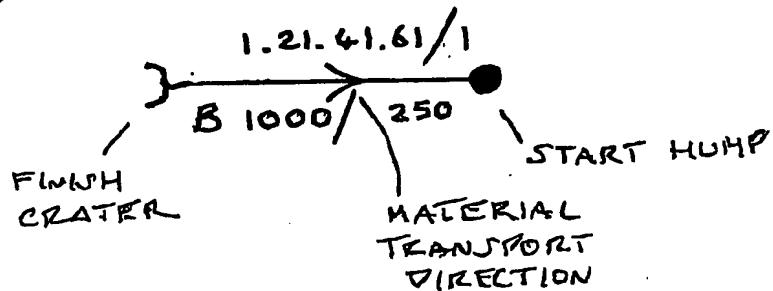
⑤  $n$  x SUPERIMPOSED SWIPEs  
 $n$  x mixed material  
 $n-1$  x mixed material



⑥  $n$  x SUPERIMPOSED SWIPEs

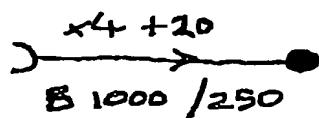


⑦ NOTATION SYSTEM



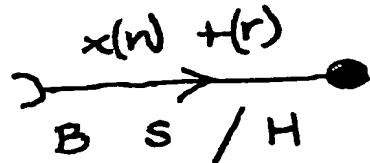
SWIPEs 1, 61, 21, AND 41, FROM A REPEAT PATTERN OF 1000 SWIPEs. SPECIFIC SWIPE PATTERN 'B'. HUMP #1 OF 250

⑧ NOTATION SYSTEM



GENERIC NOTATION FOR EACH OF 250 HUMPS AS PER FIG ⑦

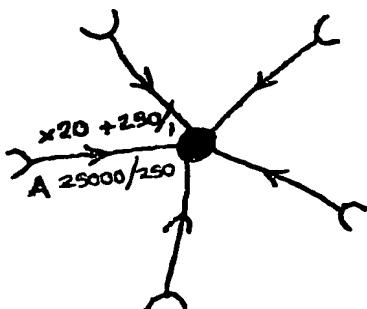
## NOTATION SYSTEM



'n'  
'r'  
H  
S

SWIPE'S AT  
EACH LOCATION  
NO OF SWIPE'S  
BEFORE REVISIT  
NO OF HUMPS  
NO OF SWIPE'S  
IN REPEAT PATTERN

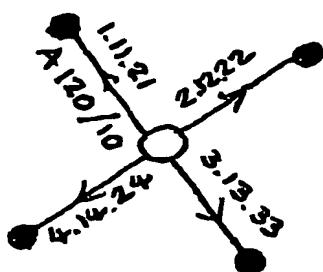
$\times 6$  SUPERIMPOSED 'HUMP' MOTIF  
 $\times 6$  - 'SUPER HUMP'



$n = 20$   
 $r = 250$   
 $H = 250$   
 $S = 25000$

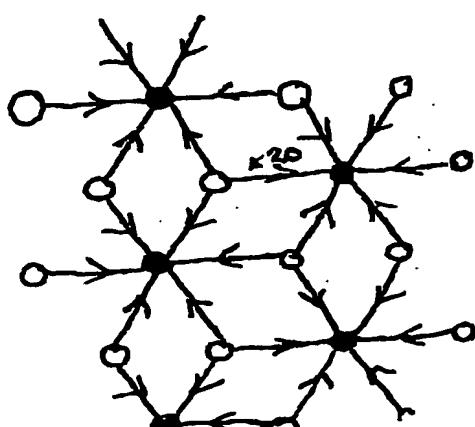
SUPERIMPOSED

CAVITIES, OR, HOLES  
'SUPER-HOLE' MOTIF



$n = 3$   
 $r = 10$   
 $H = 10$   
 $S = 120$

(12)



NETWORK OF  
 $\times 3$  SUPERHOLES  
 $\times 6$  SUPER HUMPS  
MADE WITH  $\times 20$   
SWIPE'S

MOTIF AS FIG 10,

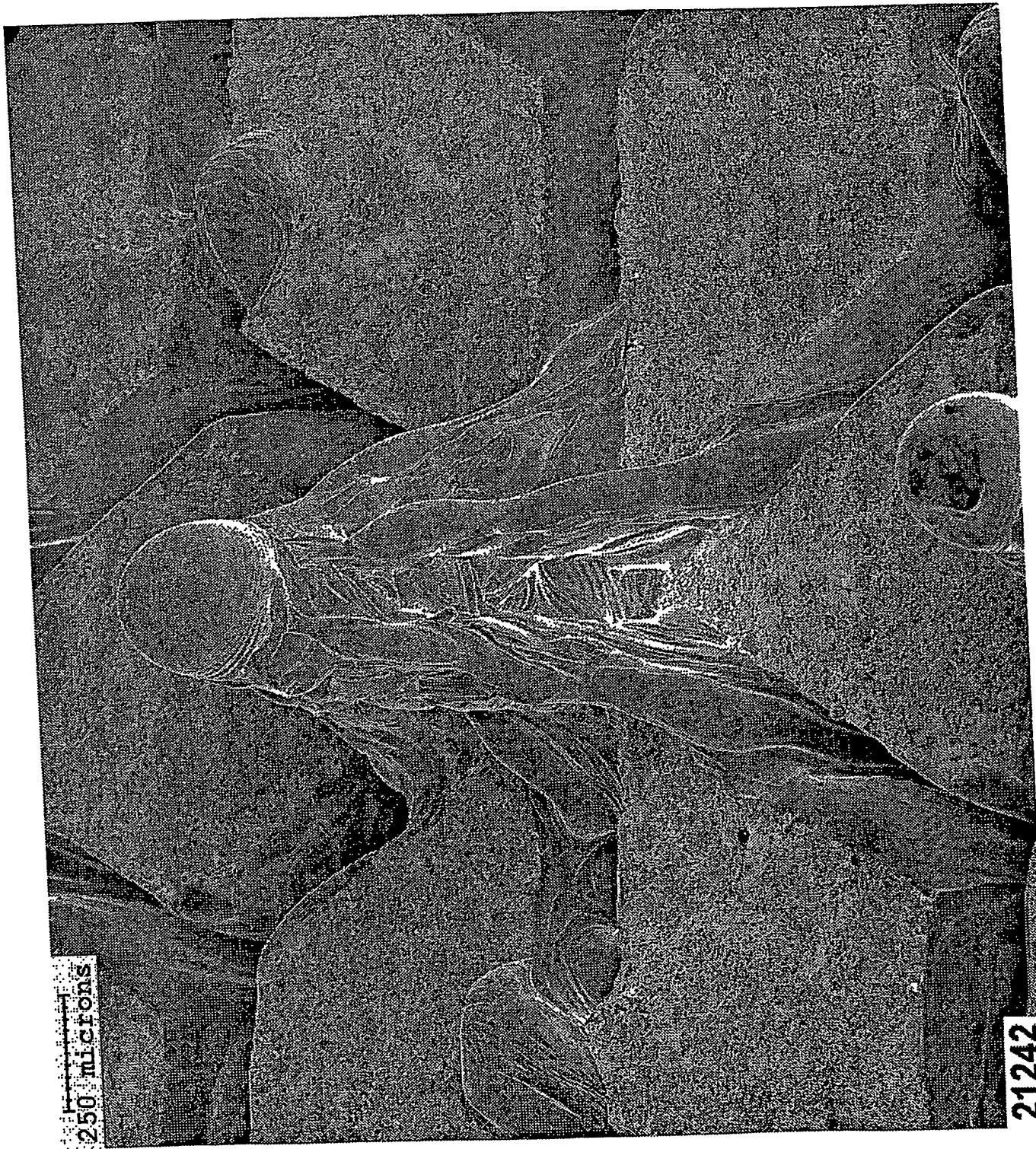


Fig 13.  $x \sim 40$  swipe/ $x6$  superhump/ $x3$  superhole result. Austenitic stainless steel.

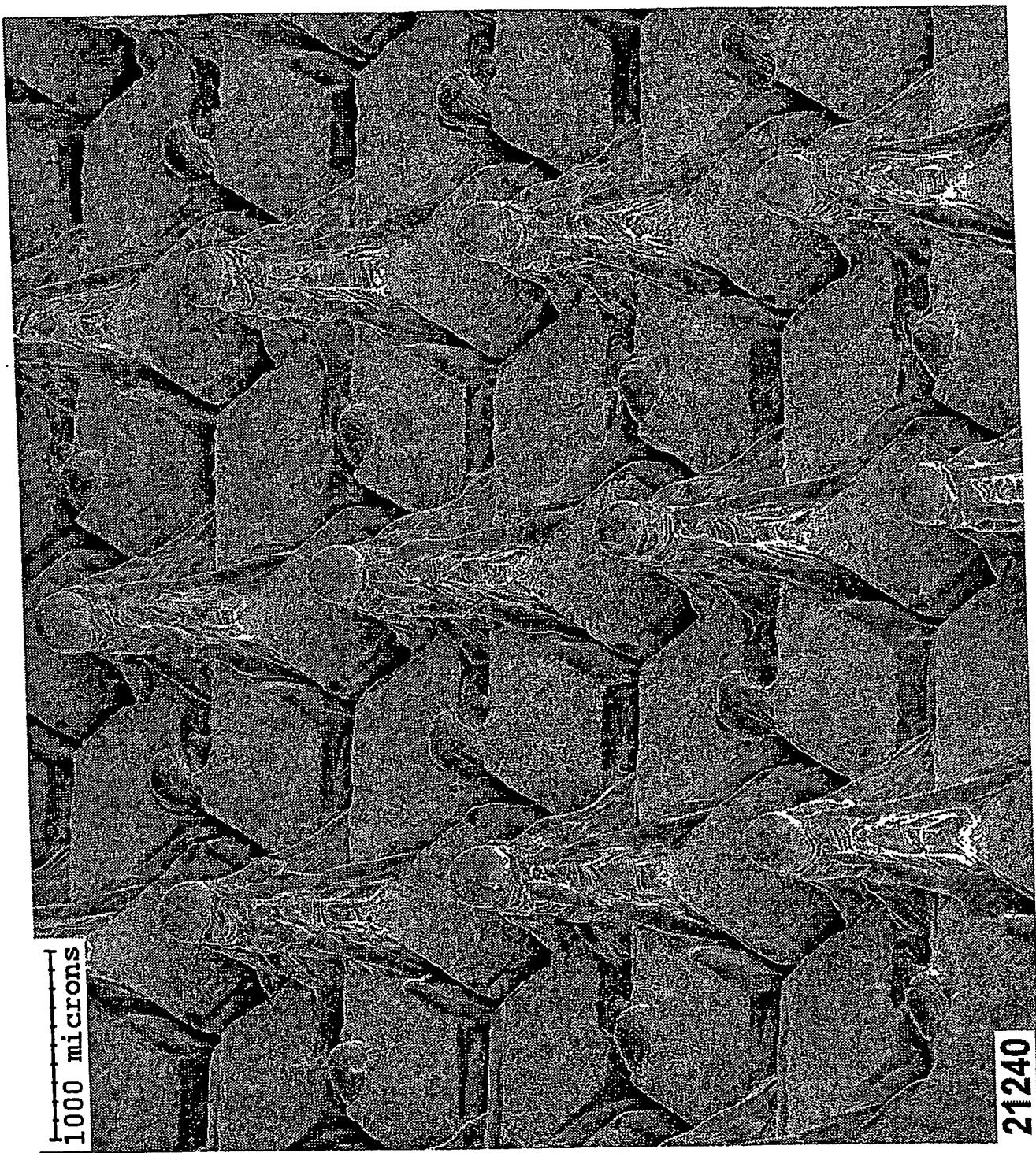


Fig 14. As per fig 13, but a general view.

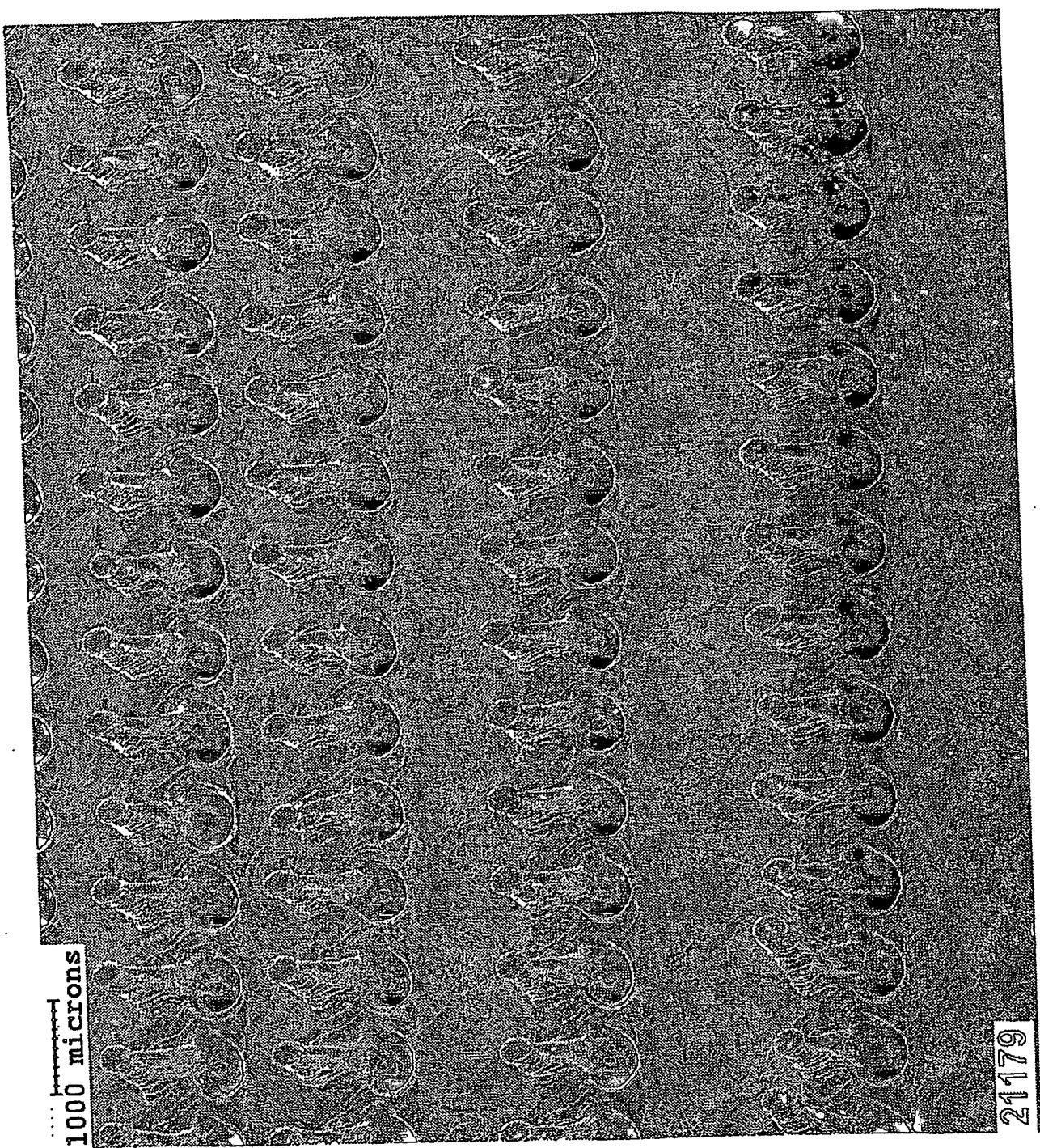


Fig. 15.  $x \sim 100$  Hump/holes.

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